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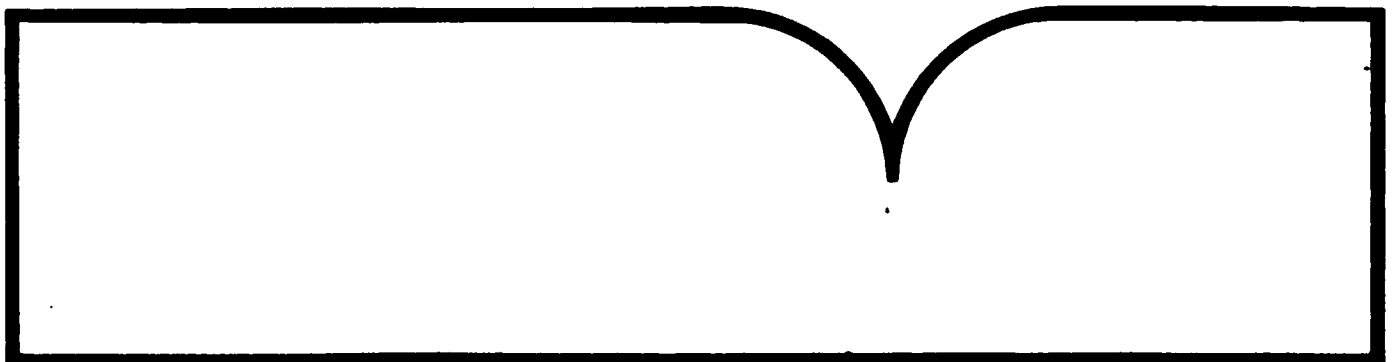


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W.J. Senus

Defense Mapping Agency
Washington, D.C.

February 1982



U.S. Department of Commerce
National Technical Information Service
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<p>The NAVSTAR Global Positioning System (GPS) when fully developed will provide world-wide, all weather, continuous, highly accurate radio navigation support to the full spectrum of military uses. In addition it has the potential to revolutionize the navigational capability of the civil sector as well. The Defense Mapping Agency, in conjunction with other government agencies in sponsoring the development of GPS user equipment which will benefit greatly the Mapping, Charting, and Geodesy (MC&G) Community. Among these developments are GPS receivers for geodetic survey applications.</p>		

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GLOBAL POSITIONING SYSTEM (GPS) GEODETIC RECEIVERS

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BIOGRAPHICAL SKETCHES

Walter J. Senus is the Chief Scientist within the Advance Technology Division at the Defense Mapping Agency Headquarters in Washington, D.C. Dr. Senus received his Bachelor and Master of Science degrees in Physics from Syracuse University in 1967 and 1971 respectively and his PhD in Geodesy and Geophysics from the University of Hawaii in 1976. His responsibilities as Chief Scientist include the development of techniques to utilize the Global Positioning System (GPS) as a geodetic tool to be applied against the many diverse Mapping, Charting and Geodesy (MC&G) requirements to which DMA must respond.

ABSTRACT

The NAVSTAR Global Positioning System (GPS) when fully developed will provide world-wide, all weather, continuous, highly accurate radio navigation support to the full spectrum of military uses. In addition it has the potential to revolutionize the navigational capability of the civil sector as well. The Defense Mapping Agency, in conjunction with other government agencies in sponsoring the development of GPS user equipment which will benefit greatly the Mapping, Charting, and Geodesy (MC&G) Community. Among these developments are GPS receivers for geodetic survey applications.

GPS geodetic receivers are being built around several operating modes, each of which has its advantages. The GPS program as well as the various techniques being pursued are briefly reviewed. Data collected to date is reported which indicated excellent performance both in the point positioning mode and in the distance difference mode of operation. Further the anticipated improvement in measurement accuracy will be provided with a corresponding reduction in time required to occupy a measurement site and therefore offers operational cost reductions.

THE NAVSTAR GLOBAL POSITIONING SYSTEM

The NAVSTAR Global Positioning System (GPS) is a satellite based navigation system designed to provide continuous all weather three dimensional position and velocity, and accurate timing to properly equipped users on a worldwide basis¹. The operational system available in the late 1980's will consist of 18 to 24 navigational (NAVSTAR) satellites, distributed in circular orbits with an inclination of 55°. The configurations and the high altitude of the orbits insure that at least four satellites are "in view" of the user.

NAVSTAR GPS is a joint service program with the Air Force as the executive service. The system evolved from Air Force and Navy programs which were initiated in the mid-1960's. The development program for the system is divided into three phases. The initial phase consisted of six satellites launched in 1978-1979, distributed in two orbit planes having an inclination of 63° to provide system evaluation and testing over the southwestern United States. The system is currently in the second phase during which extensive operational testing will occur. The third phase will result in the full up operational system. The NAVSTAR GPS operates on two L-band frequencies, 1575.42MHz (L1), and 1227.6 MHz (L2). The system is made up of three major segments which include space, control and user equipment segments. Figure (1) shows the inter relationship of these three major segments.

The Space Segment when fully operational will consist of a constellation of at least 18 satellites in six orbital planes, with three satellites in each plane. The satellites will operate in circular 20,200 kilometer orbits at an

inclination of 55° and with a 12-hour period. The overall constellation will be configured to provide a minimum of four satellites in view to a user at all times. 2

The Control Segment is comprised of monitor station's (MS) which perform routine tracking of the NAVSTAR satellites and provide observational data to the Master Control station (MCS). The MCS incorporates the observations from all MS and all NAVSTAR satellites to determine and predict the satellites' ephemerides and clock parameters.

The NAVSTAR User Segment consists of User Equipment which will measure the range and range rate to the GPS satellites. Figure 2 shows how this user equipment utilizes the broadcast data to develop position and velocity information. The nominal navigation performance of a suitably equipped GPS user, when the complete NAVSTAR constellation is operational, will be 16 meters SEP (Spherical Error Probable) world-wide.

The operational application's of the GPS are extensive with Figure 3 offering a sample compilation of these.

GPS Geodetic Receiver. Although the navigation performance of the GPS is truly revolutionary the utility of GPS to the geodetic survey community certainly requires significant improvement in system's positioning capability². Several schemes for exploitation have been proposed. One group of investigators suggest that the GPS signal be monitored from two locations which define the endpoints of a baseline³. The simultaneous reception of signals at these locations, properly tagged in time, can then be cross correlated using processing techniques suitable to Very Long Baseline Interferometry Figure 4. Results which have been reported to date indicate 2-5 cm residual error when measurements were conducted over a calibrated baseline⁴. This technique offers substantial promise to the geodetic community especially to those elements of the community who may not have full-access to the GPS precision signal. Certain limitations that exist with this concept as it is currently proposed are the need for two monitoring receivers, the inability to establish a single point position as is currently done with transit based technology and the apparent large computer requirement driven by the data correlation requirement.

A second school of development has opted to pursue a technical approach which has as its basis the measurement of the doppler shift of the GPS signals as the satellites pass overhead. This later approach seems to require a more sophisticated receiving system in that the receiver must receive the GPS signal, reconstruct the GPS carrier frequency which will contain the doppler phase information. Observations made over a baseline of 100 or more kilometer can produce distance measurements with an accuracy of better than 10cm⁵. Subsequent to these Evans et al conducted a test of the sensitivity of the concept using experimental geodetic receiving equipment used to determine the relative positions of two receiving systems⁶. In this test periodic movements of the receiving antenna were introduced over a triangular pattern approximately 2 meters on each side. The results indicated that the relative position's of the antennas can be determined to 5 cm.

PROTOTYPE GEODETIC RECEIVER

Specifications were written for a prototype geodetic receiver which will meet the geodetic and geophysical requirements of U.S. Government agencies. The lead agency for development of the system is the Naval Surface Weapons Center under a task assigned by the Defense Mapping Agency. The Applied Physics Laboratory of Johns Hopkins University played a key role in setting the detailed specifications for the receiver (APL, 1980). The system will be developed under the guidance of a working group chaired by the Defense Mapping Agency Hydrographic/Topographic Center in response to the Interagency Coordination Plan of National Geodetic Survey, The National Aeronautics and Space Administration, The Defense Department, and United States Geological Survey, with the support and meeting the requirements of the Bureau of Land Management. The components of the system are receiver, computer/recorder/display, antenna/preamplifier, and on option can include communications modem, weather station, radiometer, and off-line computer

Figure 5. The first three items, the receiver, computer and antenna will be used in all applications and will display real-time absolute positions, record data for post-processing, and include ports to receive weather data and provide data to a control computer, if desired. Recently a contract was awarded to the Texas Instruments Co. in Lewisville, Texas for the fabrication of prototype GPS geodetic receivers. The first of these receivers will be delivered in early 1983 with this initial contract allowing for the fabrication of up to 10 units.

SUMMARY OF GEODETIC RECEIVER ACCURACY

The accuracy of absolute positioning is limited by the expected uncertainties in the orbits and clocks of the NAVSTAR satellites. The expected accuracy improves from 10 to 15 meters for an instantaneous fix to better than two meters after a few hours of observation. A substantial portion of the orbit and clock errors on the relative position of two or more locations can be eliminated simply by differencing positions computed from near simultaneous tracking of the NAVSTAR satellites. Geometry and environmental differences will lead to actual observational differences at the sites. These differences can be minimized and improved by using techniques similar to those incorporated in very long baseline interferometry.

CONCLUSION

The development of the GPS as a tool for geodetic applications offers substantial rewards. It offers the potential of doing precise geodetic measurements over a variety of distances as well as at point positions. Further it offers the potential for doing these measurement in a time much faster than previously possible. Figure 6 summarizes some of the evolutionary steps which have marked the application of satellite based measurements to geodetic problems. As indicated GPS will be a significant improvement.

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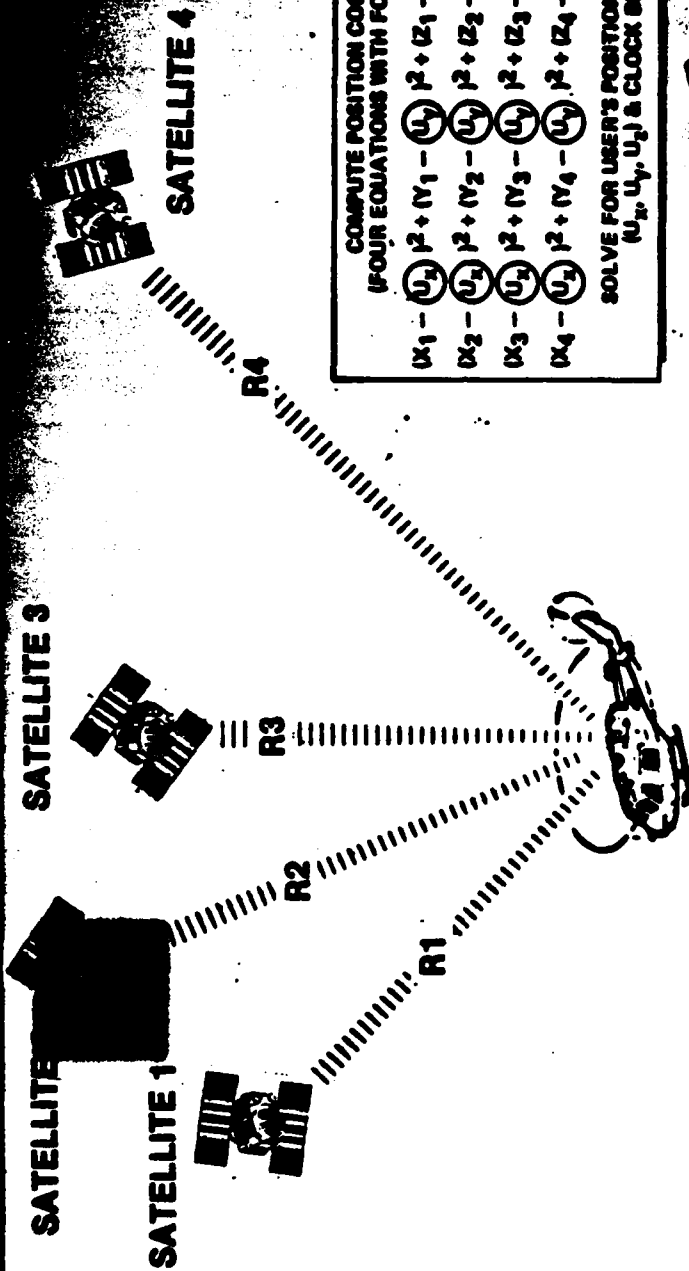
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GPS &
SIGNAL
MONITOR
STATIONS
ALASKA
HAWAII
GUAM
VAFB
EASTERN
CONTROL
STATION



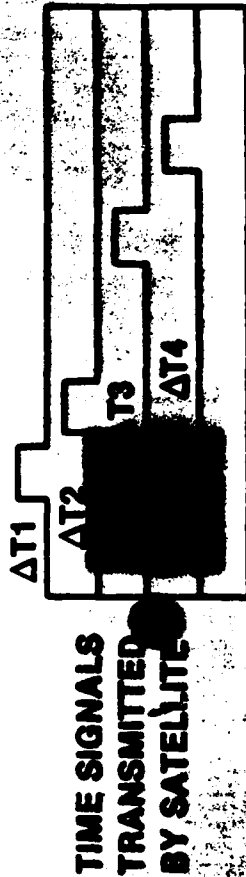


COMPUTE POSITION COORDINATES
(FOUR EQUATIONS WITH FOUR UNKNOWN)

$$\begin{aligned} x_1 - (u_1)^2 + (v_1 - (u_1)^2 + (z_1 - (u_1)^2 - (c_1)^2) \\ x_2 - (u_2)^2 + (v_2 - (u_2)^2 + (z_2 - (u_2)^2 - (c_2)^2) \\ x_3 - (u_3)^2 + (v_3 - (u_3)^2 + (z_3 - (u_3)^2 - (c_3)^2) \\ x_4 - (u_4)^2 + (v_4 - (u_4)^2 + (z_4 - (u_4)^2 - (c_4)^2) \end{aligned}$$

SOLVE FOR USER'S POSITION COORDINATES
(u_x, u_y, u_z) & CLOCK BIAS (c_u)

COMPUTE FOUR PSEUDO-RANGE VALUES



$R1 = C \times T1$

$R2 = C \times T2$

$R3 = C \times T3$

$R4 = C \times T4$

(C = SPEED OF LIGHT)

OPERATIONAL APPLICATIONS



NAVIGATION

ENROUTE--LAND, SEA, AIR
TERMINAL--AIRPORT, HARBOR
3D INSTRUMENT APPROACH
SPACE NAVIGATION
TIME SYNCHRONIZATION

POSITIONING

RANGE INSTRUMENTATION
GEODESY & SURVEY
COLLISION AVOIDANCE
SEARCH & RESCUE
INS UPDATING
TARGET POSITIONING
PHOTO MAPPING &
TARGETING

Interferometric Concept

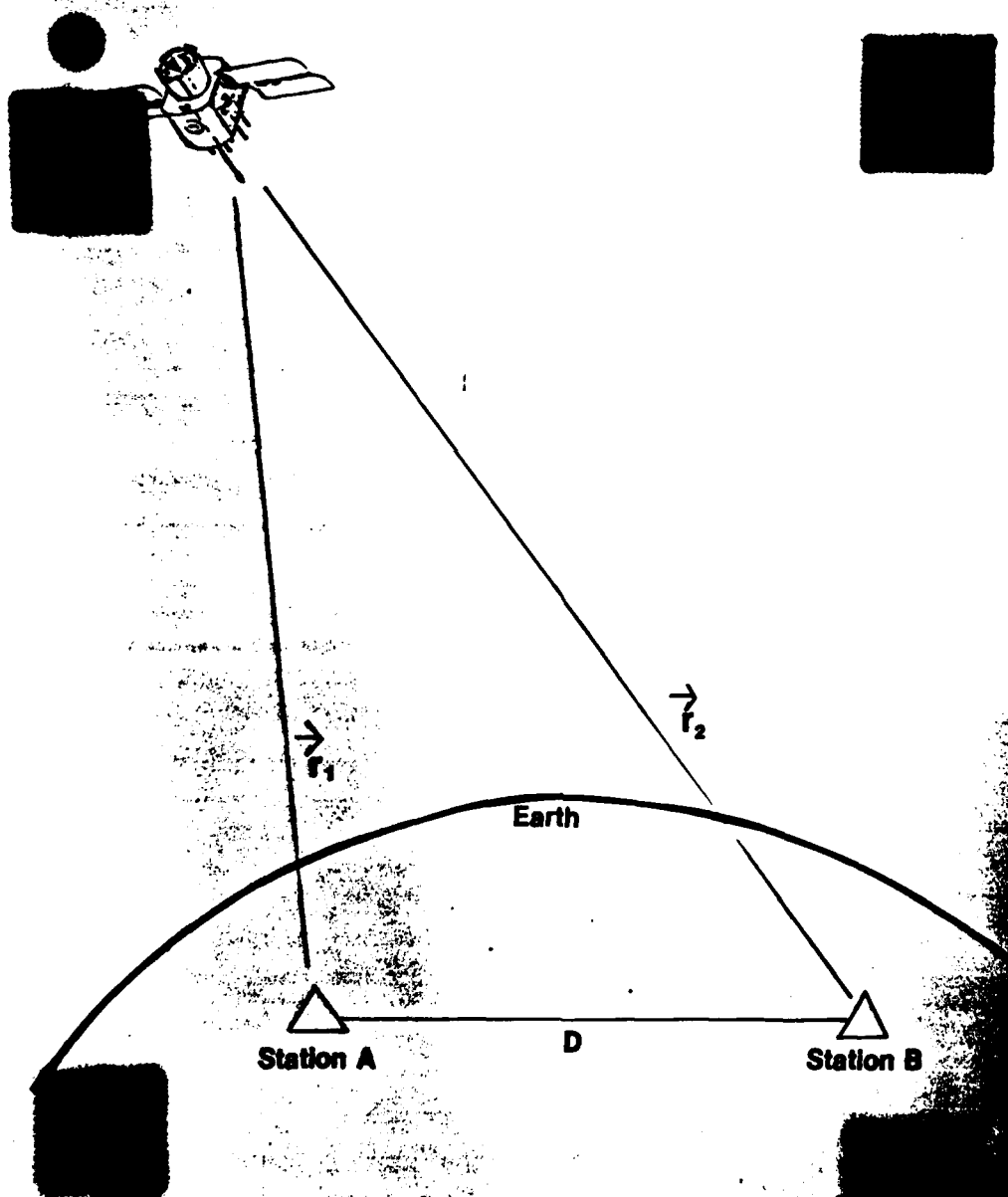


FIG 4

GPS Geodetic Receiver System Functional Diagram

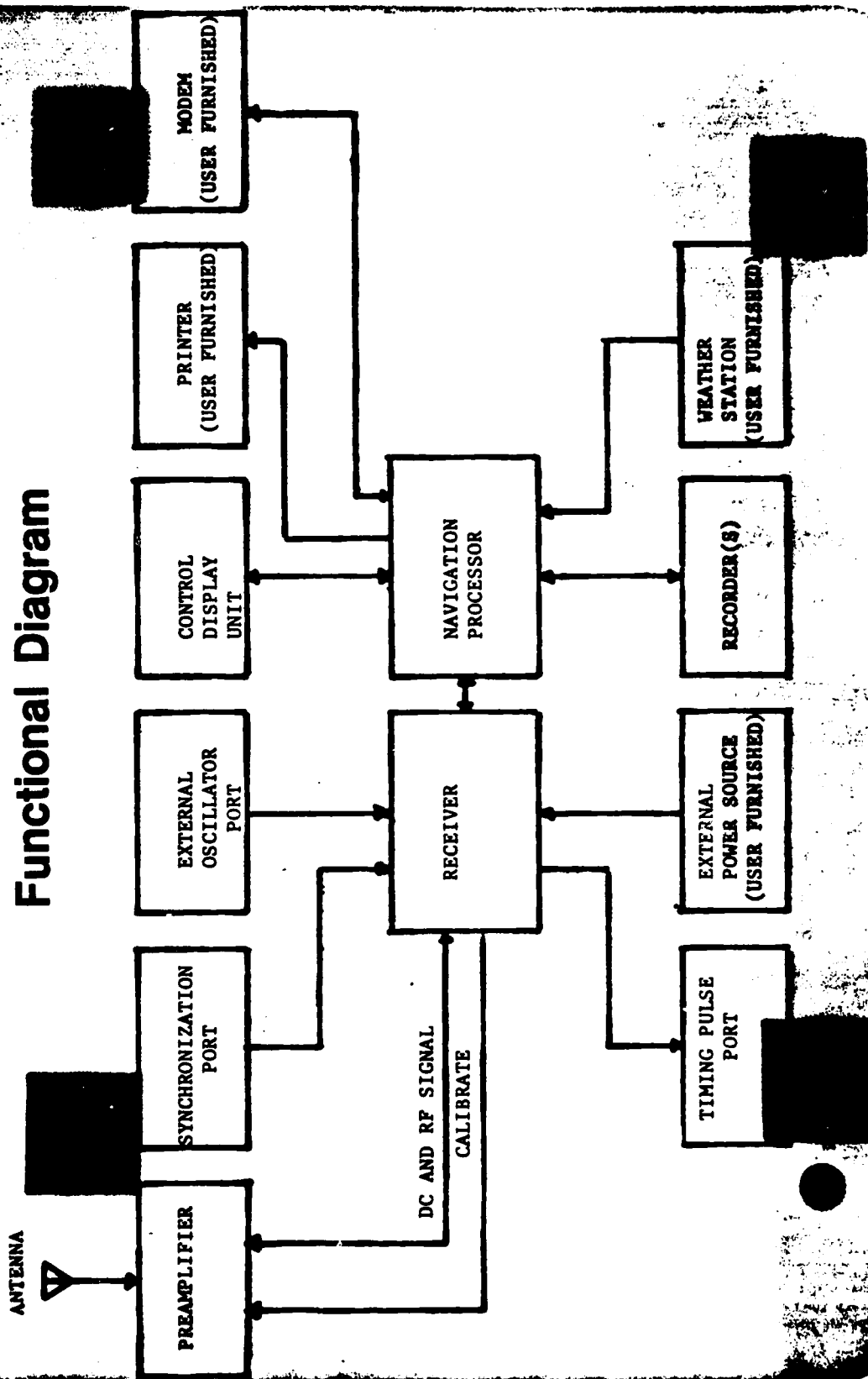


FIG 5

Method	Accuracy (1σ)	Note
Conventional survey Techniques	$10^{-6} \times \text{distance}$ $10^{-5} \times \text{distance}$	Special projects <100 km (Environmental limitations)
Transit satellite		
• Point positioning	~1 m	Long measurement period (35-40 passes), <200 km
• Distance measurement	<1 m	
GPS satellite		
• Point positioning	<1 M	Near real time
• Distance measurement	~2-5 cm	



7

